ACL Injury Prevention: Considerations for Children and Adolescents

Susan Sigward PhD, PT, ATC
Human Performance Laboratory
University of Southern California
ACL Injury

• Season ending/ “Career” ending
  – 82% return to physical activities/sports
  – 44% return to competitive sports
• Increased risk for injury
  – 12%-27% within 5-10 yrs. post-ACLr
• Long term joint health
  – 3x greater chance of developing knee OA

Children and Adolescents

Number of Injury Claims

Age

ACL Injury-Male  ACL Injury-Female  Knee Injuries


USC Division of Biokinesiology and Physical Therapy
ACL Injury

- Increased incidence of non–contact ACL injuries in female athletes
  - Female 3 – 8 times greater than male

Arendt, 1995; Agel, 2005; Malone, 1983
Mechanism of Injury

Non-contact

• 70% of ACL injuries results from situations that do not involve contact to the knee

Olsen, 2005; Boden, 2000; McNair, 1990
Mechanism of Injury

Qualitative description

• Analyzed from video tape and questionnaire
  – Deceleration/Change in direction
  – Knee flexion angle 0° – 30°
  – Tibial rotation and/or varus/valgus position

Olsen et al, 2004; Boden, 2000
Mechanism of Injury

*In vitro*

- Knee flexion (0° - 40°)
  - Anterior tibial force
    Markolf, 1990
  - Varus/valgus torque
    Markolf, 1990; Durselen, 1995
  - Internal > external rotation torque
    Markolf, 1990
Mechanism of Injury

*In vitro*

- Knee flexion (0°- 40°)
  - Combined loading
    - Anterior tibial force and valgus

Markolf, 1995
Biomechanical/Neuromuscular

Non-contact ACL injuries occur during dynamic situations

What are the effects of movement patterns on risk for injury?

Can movement patterns/performance be changed to decrease risk of injury?
Bad Knee Mechanics

Anterior shear force

Valgus torque

USC Division of Biokinesiology and Physical Therapy
Bad Knee Mechanics

At small knee flexion angles (0-40°): Quadriceps contraction translates into greater anterior shear forces.

*ACL is more vulnerable to transverse and frontal plane loads.

Taken from: Kernozek et al. *Critical Rev Bio Eng*, 2013

USC Division of Biokinesiology and Physical Therapy
Bad Knee Mechanics

Prospective
Knee valgus loading predicts ACL injury risk in females

ACL Injured:
- knee valgus moments were 2.5 x greater
- knee valgus angles were 8.4° greater

Hewett et al., 2005
Bad Knee Mechanics

A. 

B. 

USC Division of Biokinesiology and Physical Therapy
Mechanism of Injury

Landing

Cutting

USC Division of Biokinesiology and Physical Therapy
Landing

Control deceleration of the COM in the vertical direction

Sagittal Plane !!!
- Hip extensors
- Knee extensors
- Ankle plantar flexors

What contributes to “bad” knee mechanics?

Limited engagement in the sagittal plane results in increased reliance on the frontal plane.
Low flexion landing strategy

Increased reliance on knee extensors relative to hip extensors
Female athletes who use less hip & knee flexion during landing also exhibit higher frontal plane loads at the knee.
Decreased Knee and Hip Flexion

Knee extensor moment and power
Hip extensor moment and power

Increased Knee Extensor Moments
Increased Quad (VL) Activation
Decreased Hip Extensor Moments

Knee valgus moments 2 X greater

Pollard, Sigward and Powers, Clin Biomech. 2010
Sagittal and Frontal Plane

Low flexion landing strategy
“Stiff Landing”

Increased frontal knee loading
Children and Adolescents

Knee extensor moment
Hip extensor moment

F: 12.5 yrs M: 13.3 yrs
F: 15.7 yrs M: 15.6 yrs
Children and Adolescents

Knee valgus moment

-0.05  0.00  0.05  0.10  0.15

prepubertal  pubertal  post pubertal  adult

USC Division of Biokinesiology and Physical Therapy
Cutting

Control deceleration of the COM in a horizontal direction

+ Redirect the COM

Transverse and Frontal Planes !!!
Cutting

Control deceleration of the COM in a horizontal direction

+ Redirect the COM

USC Division of Biokinesiology and Physical Therapy
61 Female Soccer Players
- Average knee valgus moment group (n=38)
- High knee valgus moment group (n=23)

Hip and knee angles, Foot Position and GRFs
How’s her technique or mechanics contributing to high loads or low loads?

Knee Frontal Plane Moment

USC Division of Biokinesiology and Physical Therapy

Sigward and Powers, Clin Biomech. 2007
Knee Frontal Plane Moment

Valgus

Nm/kg-bwt

Varus

-2.5

-2

-1.5

-1

-0.5

0

0.5

13579 1 1 1 3 1 5 1 7 1 9 2 1 2 3 2 5 2 7 2 9 3 1 3 3 3 5 3 7 3 9 4 1 4 3 4 5 4 7 4 9 5 1 5 3 5 5 5 7 5 9 6 1

Subject

Excessive Valgus Moment Group

Normal Moment Group

Sigward and Powers, Clin Biomech. 2007
Contributors

High knee valgus moment:
- Greater
  - Hip Abduction
  - Hip Internal Rotation
  - Internal Foot Progression Angle
  - Peak Lateral Ground Reaction Force

Together they explained 49% of the variance in knee valgus moment

Sigward and Powers, Clin Biomech. 2007
sagittal plane

frontal & transverse plane
**Knee Valgus Moment**

**Children and Adolescents**

- **F: 10.2 yrs**  
- **M: 11.4 yrs**

**Sigward et al., Med Sci Sports Exerc, 2012**
Valgus Knee Loading

Children and Adolescents

Landing

-0.01 0.04 0.09 0.14
pre-pubertal  pubertal  post-pubertal  adult

Cutting

1.1 1.3 1.5
pre-pubertal  pubertal  post-pubertal  adult
Children and Adolescents

Valgus Knee Loading

Landing

Cutting
Children and Adolescents

Why is valgus moment higher in the pre-pubertal group?

- Greater
  - Hip Abduction
  - Hip Internal Rotation
  - Internal Foot Progression Angle
- Peak Lateral Ground Reaction Force
Children and Adolescents

Lateral Ground Reaction Force

Vertical Ground Reaction Force

Posterior Ground Reaction Force

over 2X greater

Pre-pubertal Children

• Why do pre-pubertal children perform cutting tasks with greater forces?
Pre-pubertal Children

• Locomotor competence
  – Childhood games
  – Athletic skills

• Fundamental motor skills
  – Basis of more complex movement patterns
Pre-pubertal Children

- Locomotor competence
  - Childhood games
  - Athletic skills

- Fundamental motor skills
  - Basis of more complex movement patterns
    - Self-paced, discrete or repetitive movements
    - *How children control their body to achieve these tasks?*
Control of Body Momentum

How do they control body momentum?
• Deceleration during running
• Change in direction

Momentum = mass \times velocity
Experimental Task

Verbal command:
“Run as fast as you can and come to a complete stop”

**Experimental Task**

**Initial Position**

**Task Direction**

**RUN**

**Timing Gates**

21 m

**Verbal command:**

“Run as fast as you can all the way”

**Maximum velocity:** $V_{max}$

---


---

**USC Division of Biokinesiology and Physical Therapy**
Cesar and Sigward. *Human Mov Sci, 2016*
Children took fewer/longer steps
COM Position-control of posture

Where do we position our COM to decelerate our body?

Low and back=
Position it posterior to the base of support
Lower it vertically
COM posterior position

<table>
<thead>
<tr>
<th></th>
<th>Adults</th>
<th>Children</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Posterior Position</td>
<td>0.30 (0.04)</td>
<td>0.14 (0.08)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>


USC Division of Biokinesiology and Physical Therapy
Postural control
ADULTS
Deceleration

Different Strategies

CHILDREN
Propulsion (?)

- Approached at 76 %Vmax
- More and shorter steps
- COM
  - More posterior
  - Lower

- Relatively faster (85 %Vmax)
- Long steps (108% LL)
- COM
  - Anterior to their foot 1/3 time
  - Higher than standing height

Postural control

- Children approach deceleration tasks at a faster relative velocity than adults
- Less stable mechanics
- Equally successful

(Cesar and Sigward, 2015)
Pre-pubertal Children

- Why do pre-pubertal children perform cutting tasks with greater forces?
- Does it matter?

F: 10.2 yrs M: 11.4 yrs
Pre-pubertal Children

• Why do pre-pubertal children perform cutting tasks with greater forces?
• Does it matter?

Neurodevelopment

Growth and maturation of the nervous system
Injury prevention
Special Considerations

• Most effective training will take into consideration typical development and individual variations
Children and Adolescents

- Age/Maturation
  - Physical growth
  - Neurodevelopment
  - Social development
Neurodevelopment

Growth and maturation of the nervous system
– Sensory and perceptual abilities
  • Neurologic
  • Sensory-perceptual
  • Cognitive
  • Psychosocial or Emotional

Patel et al, 2002 *Pediatric Clinics of North America*

USC Division of Biokinesiology and Physical Therapy
Neurodevelopment

Development within domains

- Fundamental motor skills
  - Basis of more complex movement patterns

Gross motor skills: single plane → multiple joint → multiple muscle groups → multiple planes → multiple joint across planes

Neurodevelopment

Development within domains

• Fundamental motor skills
  – Basis of more complex movement patterns
  Gross motor skills: single plane → multiple joint → multiple muscle groups → multiple planes → multiple joint across planes

Human Performance Laboratory

Neurodevelopment

Integration across domains

• Visual-motor
  – Catching, kicking, throwing

  *Sport specific skills*

Images taken from:
- http://4.bp.blogspot.com/-j024x1vUtwo/TKfxr8BbVtl/AAAAAAAABYw/iKarocupKNC/s1600/IMG_3074.JPG
- http://1.bp.blogspot.com/-BnfpkBblFUw/UI7zbsu9mZI/AAAAAAAARNw/8XnAzRQJX_Q/s1600/IMG_4272.JPG

Patel et al, 2002 *Pediatric Clinics of North America*
Neurodevelopment

“Although different developmental milestones are recognized at specific ages, appearance of these milestones often varies considerably in different children; however, the sequential nature of development remains the same in normally developing children”

Patel et al, 2002 *Pediatric Clinics of North America*

USC Division of Biokinesiology and Physical Therapy
Children and Adolescents

Cutting

Body/postural control
Coordination across joints and planes
Perceptual motor planning

F: 10.2 yrs
M: 11.4 yrs
Adolescents

• Physical growth
  – Puberty
    • Peak height and weight velocity
      – Maximal rate of growth
      – Increases in strength (boys > girls)
      – Discoordination in new (physical plant) environment

Taken from: http://www.mun.ca/biology/desmid/brian/BIOL3530/DEVO_13/ch13f09.
Children and Adolescents

Landing
Coordination across joints in a single plane of movement

- Pre-pubertal = Children

Pubertal
F: 12.5 yrs
M: 13.3 yrs

Post-pubertal
F: 15.7 yrs
M: 15.6 yrs
Common Components of Successful ACL Injury Prevention Programs

- Technique Training
- Strength Training
- Plyometric Training
- Balance Training
- Agility Training

Common Components of Successful ACL Injury Prevention Programs

- Balance Training
- Agility Training
- Technique Training
- Strength Training
- Plyometric Training

Children
- Pre-pubertal

Adolescents
- Pubertal
- Post-pubertal
Balance

- size of the surface
- stability of the surface
- external perturbation or stimulus
- multitasking: catching or throwing
- position of the head during the task
Agility

• Rapid whole-body movement with changes in velocity and direction in response to a stimulus
Agility

- Agility
  - Speed
  - Footwork
  - Plane of movement
  - Direction of movement
Agility

Combines physical qualities such as strength, power, balance and speed with cognitive components:

– Perception
– Anticipation
– Motor planning
– Reaction
Common Components of Successful ACL Injury Prevention Programs

- Balance Training
- Agility Training
- Technique Training
- Strength Training
- Plyometric Training

Children
Pre–pubertal

Adolescents
Pubertal
Post-pubertal
Strength Training

• Goal
  – Adaptation- biological adjustment to stress

• Mechanism
  – Overload-apply a greater than normal stress to the muscle
  – Specificity- the stress should be specific to adaptation desired
Strength Training

• Hypertrophy
  – Puberty → Adult

• Neural adaptation
  • Activation, Inhibition
  • Recruitment patterns
  – Pre puberty
Strengthening

• Resistance Exercises
  – Youth training guidelines
    Supervision
    Safety
    Balance
    Progression
    Moderation

Faigenbaum et al., J Strength Cond Res 2009
Human Performance Laboratory

- Provide qualified instruction and supervision
- Ensure the exercise environment is safe and free of hazards
- Start each training session with a 5- to 10-minute dynamic warm-up period
- Begin with relatively light loads and always focus on the correct exercise technique
- Perform 1–3 sets of 6–15 repetitions on a variety of upper- and lower-body strength exercises
- Include specific exercises that strengthen the abdominal and lower back region
- Focus on symmetrical muscular development and appropriate muscle balance around joints
- Perform 1–3 sets of 3–6 repetitions on a variety of upper- and lower-body power exercises
- Sensibly progress the training program depending on needs, goals, and abilities
- Increase the resistance gradually (5–10%) as strength improves
- Cool-down with less intense calisthenics and static stretching
- Listen to individual needs and concerns throughout each session
- Begin resistance training 2–3 times per week on nonconsecutive days
- Use individualized workout logs to monitor progress
- Keep the program fresh and challenging by systematically varying the training program
- Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep
- Support and encouragement from instructors and parents will help maintain interest
Human Performance Laboratory

• Provide qualified instruction and supervision
• Ensure the exercise environment is safe and free of hazards
• Start each training session with a 5- to 10-minute dynamic warm-up period
• Begin with relatively light loads and always focus on the correct exercise technique
• Perform 1–3 sets of 6–15 repetitions on a variety of upper- and lower-body strength exercises
• Include specific exercises that strengthen the abdominal and lower back region
• Focus on symmetrical muscular development and appropriate muscle balance around joints
• Perform 1–3 sets of 3–6 repetitions on a variety of upper- and lower-body power exercises
• Sensibly progress the training program depending on needs, goals, and abilities
• Increase the resistance gradually (5–10%) as strength improves
• Cool-down with less intense calisthenics and static stretching
• Listen to individual needs and concerns throughout each session
• Begin resistance training 2–3 times per week on nonconsecutive days
• Use individualized workout logs to monitor progress
• Keep the program fresh and challenging by systematically varying the training program
• Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep
• Support and encouragement from instructors and parents will help maintain interest
Provide qualified instruction and supervision
Ensure the exercise environment is safe and free of hazards
Start each training session with a 5- to 10-minute dynamic warm-up period
Begin with relatively light loads and always focus on the correct exercise technique
Perform 1–3 sets of 6–15 repetitions on a variety of upper- and lower-body strength exercises
Include specific exercises that strengthen the abdominal and lower back region
Focus on symmetrical muscular development and appropriate muscle balance around joints
Perform 1–3 sets of 3–6 repetitions on a variety of upper- and lower-body power exercises
Sensibly progress the training program depending on needs, goals, and abilities
Increase the resistance gradually (5–10%) as strength improves
Cool-down with less intense calisthenics and static stretching
Listen to individual needs and concerns throughout each session
Begin resistance training 2–3 times per week on nonconsecutive days
Use individualized workout logs to monitor progress
Keep the program fresh and challenging by systematically varying the training program
Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep
Support and encouragement from instructors and parents will help maintain interest
Power

• The ability to produce maximum force in a short time

High risk tasks
  cutting
  landing
Power

• Plyometric Training
  – stretch-shorten cycle
    • Eccentric quickly followed by concentric
  – Goals:
    • improve maximal force production
    • maximal rate of force production
    • coordination of joint movements
Power

• Plyometric Exercises
  – Doesn’t always mean box jump

  Progress:
  - range of motion
  - responses (single vs. multiple)
  - amount of effort (maximal vs. sub maximal)
    - height
    - distance
Special Considerations

Progression

Always depends on the athlete’s level of fitness and training!

In the absence of appropriate strength and power, an athlete may adopt compensatory strategies to perform the task.

Movement quality > quantity
Special Considerations

• Most effective training will take into consideration typical development and individual variations